Bubbles in Sediments

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LONG-TERM GOAL

The physical mechanisms involved in the scattering of a linear acoustic field from a bubble, collection of bubbles, or other targets embedded in a fluid-saturated sediment are not well known. This research seeks to establish the underlying physics particularly when the acoustic field excites resonances of the scatterer(s).

OBJECTIVES

Bubbles are primary contributors to the volume scattering of sediment penetrating sonars. The physical nature of the bubble dynamics and scattering have yet to be firmly established with respect to models currently used to describe wave propagation in sediments. This research aims to establish the fundamental physical acoustics of the interaction of an acoustic field with a bubble, but the theoretical treatment is applicable to a generic target within the sediment and can be easily extended to a collections of targets.

APPROACH

The scattering from an isolated bubble or target in an infinite, isotropic, homogeneous sediment was analyzed where the sediment is modeled as either an effective fluid medium, an effective viscoelastic medium, or a fluid-saturated poroelastic medium. The transition matrix scattering formalism was used to develop the scattered acoustic field(s) such that appropriate boundary conditions are enforced to properly decouple the degrees of freedom when the scatterer and sediment are dissimilar media. The analysis includes a frequency range that encompassed the frequency associated with the monopole resonance. This resonance dominates the dynamics of a bubble even within the linear approximations used throughout this analysis for the bubble motion. The complexity of wave propagation in the choice of model for a sediment increases from a fluid model (simplest) to a fluid-saturated poroelastic model (most complex). Laboratory experiments in carefully quantified sediments were designed to validate the predictions from the transition matrix scattering formalism.

WORK COMPLETED

The transition matrix scattering formalism has been extensively developed by Waterman [1], Pao[2], and Kargl and Lim [3] when the target and host medium are identical. The development of Betti's third identity in [2] for elastic wave scattering and in [3] for poroelastic scattering was used in the theoretical work. The decoupling of degrees of freedom is discussed by Boström [4] for an elastic scatterer

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embedded in a fluid medium such that the shear degrees of freedom within the elastic material must decouple at the boundary of the scatterer. The procedure in [4] was generalized to other combinations of materials for the host and scatterer (the details are given elsewhere [5]).

Although the theoretical work is a major component of the completed effort, the planned experiments have been initiated with the construction of required equipment. A small tank facility was designed and fabricated for the experimental measurement of the interaction of an acoustic field with a bubble, collection of bubbles, or other embedded targets. Figure 1 shows the tank with nominal dimensions of 12x12x12 inches. Two Panametric V1011 transducers are aligned along their acoustic axis which permits both forward and backscattering experiments. The transducers have a usable frequency range of approximately 75 to 125 kHz with 1.5 inch diameter apertures. Other (higher) frequency ranges are possible by replacing the current set of transducers.

Fluid is drawn into the tank near the bottom (back right corner in Fig. 1) while a slight vacuum is maintained via a port on the top of the tank. This ensures the elimination of any residual gas pockets and yields nearly 100% fluid saturation of the laboratory sediment. A measurement of the volume of fluid drawn into a porous medium permits a direct measurement of the porosity of medium. The porosity is simply the volume of saturating fluid divided by the tank volume.

1. Test tank facility. The transducers are mounted in the left and right walls. The top has three access ports (capped by brass plugs) and the quick release fitting used to draw a vacuum during saturation. The vertical copper mesh in the back wall excludes the sediment from a channel that facilitates drainage.

The hydrostatic permeability (or Darcy's constant) is a crucial parameter for Biot's theory. However, a direct measure of Darcy's constant for the poroelastic medium within the tank is not easily accomplished, so a second device was designed and fabricated. Figure 2 shows the sample chamber of a constant head permeameter which consists of three pieces [6]. The top and bottom caps permit the flow of a fluid through a sediment sample where a fine copper mesh retains the sediment in the sample volume. The mesh size was chosen to accommodate medium grain-size sands (i.e., greater than 100 microns). The sample volume is defined by a polycarbonate tube with an outer diameter of 4 inches, and inner diameter of 3.28 inches. The length of the sample tube in Fig. 2 is 8.375 inches, but it can obviously be varied by changing to a different tube. The top and bottom caps are compression fitted to the tube and held in place via O-rings. The fluid enters the sample through the bottom cap and by maintaining a constant piezometric head the fluid is forced up through the sample chamber.

2. Constant Head Permeameter. The copper mesh (left) and the tube define a cylindrical volume for a sediment sample. Fluid flow rate is determined by the constant head while the actual fluid volume for a given sampling time and cylinder dimensions yield estimates for Darcy's constant.

RESULTS

Much of the FY99 effort concentrated on the theoretical development of the transition matrix formalism. Proper decoupling of modes, when target and host media are dissimilar, is essential for numerical stability. If the target and host are assumed to be of the same type of medium and then numerical limits are applied to the target to reduce the degrees of freedom (e.g., the fluid limit of an elastic target), then large wavenumber(s) and normalization coefficient(s) occur. Although the numerical limits are often acceptable for an *isolated* target, the limiting procedure may lead to numerical instabilities in a multiple scattering computation.

The theoretical analysis has introduced a new set of boundary conditions at an interface separating an elastic medium from a fluid-saturated poroelastic medium. The boundary conditions derived by Deresiewicz and Skalak [7] assume the elastic medium and the elastic component of the poroelastic medium are in welded contact. The new boundary conditions are a slip condition that suppresses the transmission of a transverse wave across the interface (i.e., the transverse component of traction is identically zero). The slip conditions may be appropriate for a target embedded in a sediment near the water-sediment interface (particularly at Navy sonar frequencies).

The analysis of preliminary data from the experiments is an on-going effort, and will be reported on elsewhere.

IMPACT/APPLICATION

Bubbles are known to occur in natural sediments. It is expected that the knowledge gained in this research will impact sediment penetrating sonar systems used in reconnaissance, mine countermeasure operations, and the interpretation of images produced by these system.

TRANSITIONS

The present research will be extended from single isolated bubbles to multiple bubbles where multiple scattering becomes important. Additionally, the infinite medium assumption imposed to isolate the resonance behavior will be removed such that the bubble will be embedded in a plane stratified medium of arbitrary composition. These extensions are expected to transition into enhancement to sonar prediction tools such as the Shallow Water Acoustic Toolset (SWAT) available from the Coastal Systems Station, Dahlgren Division, Naval Surface Warfare Center.

RELATED PROJECTS

The current research has a potential impact on the Departmental Research Initiative (DRI) entitled *High-Frequency Sound Interaction in Ocean Sediments* under the sponsorship of ONR Code 321 Ocean Acoustics. The DRI is addressing the excess penetration of a sonar signal into sediments at subcritical angles of incidence. One hypothesis for this excess penetration is the interaction of volume inhomogeneities with the evanescent field near the sediment-water interface.

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